PI-Neph Design, Scattering Measurements and Web-based Data Visualization Toolkit

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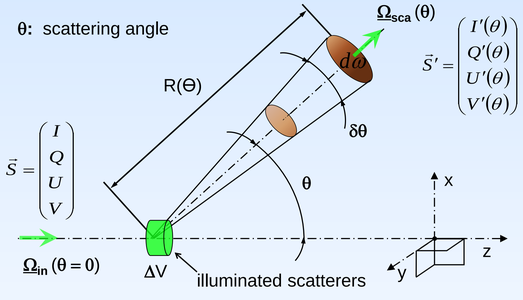
Motivation

Aerosols, clouds, and their interaction play a key role in the climate of our planet. Space based remote sensing platforms have vastly contributed to our understanding of earth's atmosphere by providing data over large temporal and spatial scales but many of the microphysical retrieval algorithms used are based on assumptions that have not yet been well validated.[1] In situ measurements of the unpolarized and polarized angular dependence of scattered light are central to both the validation of remote sensors[2] as well as obtaining accurate radiative forcing estimates[3,4]. In an effort to advance these in-situ measurements the Laboratory for Aerosols, Clouds and Optics (LACO) has developed a novel instrument concept called the Imaging Nephelometer.

Scattering Matrix - Theory

The optical scattering properties of an aerosol can be completely described by a Mueller matrix known as the scattering matrix, $\overline{\overline{P(\theta)}}$. The PI-Neph measures the first two elements of this matrix, $P_{11}(\theta)$ and $P_{12}(\theta)$.



$$\vec{S}' = \frac{\beta_S \cdot \Delta V(\theta)}{4\pi \cdot R(\theta)^2} \cdot \overline{\overline{P(\theta)}} \cdot \vec{S} \qquad \overline{\overline{P(\theta)}} = \begin{pmatrix} P_{11}(\theta) & P_{12}(\theta) & 0 & 0 \\ P_{12}(\theta) & P_{22}(\theta) & 0 & 0 \\ 0 & 0 & P_{33}(\theta) & P_{34}(\theta) \\ 0 & 0 & -P_{34}(\theta) & P_{44}(\theta) \end{pmatrix}$$

If two orthogonal linear polarization states $\overrightarrow{S_1}$ and $\overrightarrow{S_2}$ are input and the output intensities $I'_1(\theta)$ and $I'_2(\theta)$ are measured, the first two elements of the scattering matrix can be recovered.

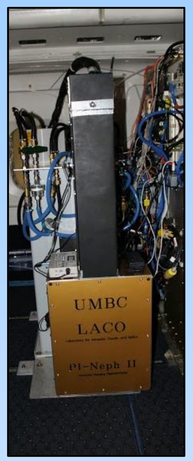
$$\vec{S}_1 = \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} \;\&\; \vec{S}_2 = \begin{pmatrix} I \\ -Q \\ -U \\ V \end{pmatrix} \Rightarrow \vec{S}'_1(\theta) = \begin{pmatrix} I'_1(\theta) \\ Q'_1(\theta) \\ U'_1(\theta) \\ V'_1(\theta) \end{pmatrix} \;\&\; \vec{S}'_2(\theta) = \begin{pmatrix} I'_2(\theta) \\ Q'_2(\theta) \\ U'_2(\theta) \\ V'_2(\theta) \end{pmatrix}$$

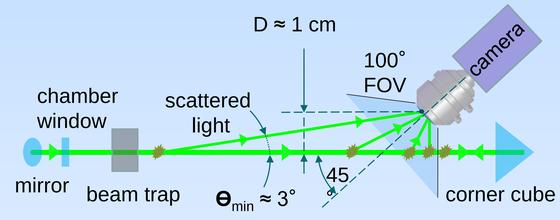
$$I'_1 = \frac{\beta_S \cdot \Delta V(\theta)}{4\pi \cdot R(\theta)^2} \cdot (I \cdot P_{11}(\theta) + Q \cdot P_{12}(\theta)) \;\&\; I'_2 = \frac{\beta_S \cdot \Delta V(\theta)}{4\pi \cdot R(\theta)^2} \cdot (I \cdot P_{11}(\theta) - Q \cdot P_{12}(\theta))$$

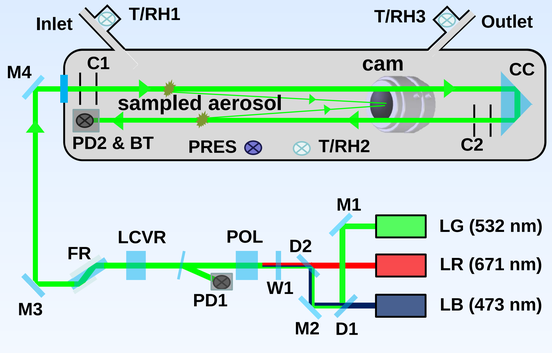
$$\beta_S \cdot P_{11}(\theta) = \frac{(I'_1 + I'_2) \cdot 4\pi \cdot R(\theta)^2}{2 \cdot \Delta V(\theta) \cdot I} \qquad \beta_S \cdot P_{12}(\theta) = \frac{(I'_1 - I'_2) \cdot 4\pi \cdot R(\theta)^2}{2 \cdot \Delta V(\theta) \cdot I}$$

Polarized Imaging Nephelometer

The imaging nephelometer is a novel polar nephelometer design that uses a high-powered laser and wide field of view optical detection system (CCD camera). This setup capitalizes on multiple scattering locations to allow for measurements of scattering matrix elements over a very wide angular range with an angular resolution that is limited only by the number of pixels contained on the CCD. A pair of these images from the CCD, corresponding to orthogonal input polarizations, can be combined to obtain and at scattering angles from 3˚ to 176˚.

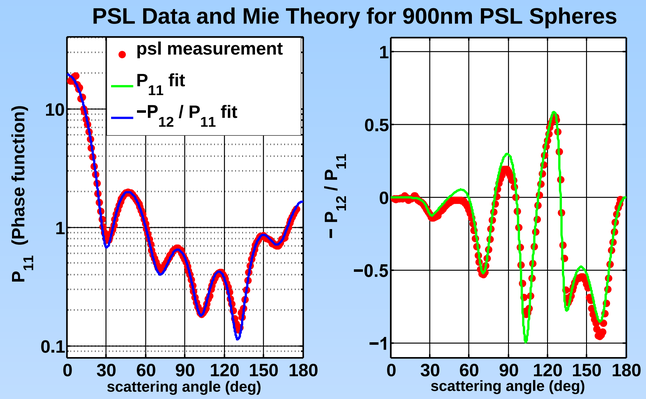




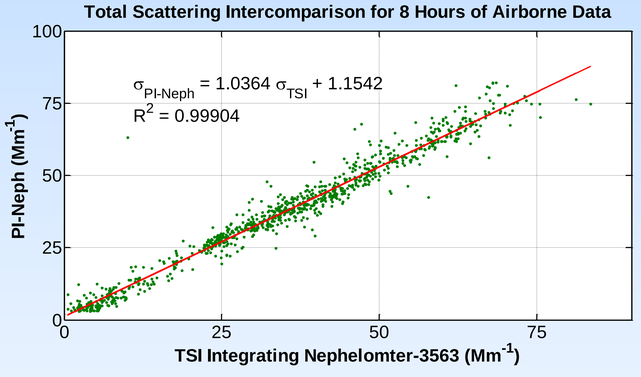


LR, LG, LB: red, green & blue laser heads
CAM: CCD camera
M1,2,3,4: laser alignment mirrors
D1,2: dichroic beam combiners
W1,2,3: windows
POL: Glan-Taylor calcite linear polarizer
PD1,2: photodiode detector assemblies
LCVR: liquid crystal variable retarder
FR: Fresnel rhomb
C1,2: beam collimator series
T/RH1,2,3: temperature & relative humidity sensors
PR: pressure sensor
CC: corner cube retroreflector
BT: beam trap assembly

PI-Neph Validation



	Manufacturer	P_{11} Derived	P_{12} Derived
Central Diameter (nm)	903 ± 12	904.4 ± 1.4	903.5 ± 1.0
Distribution Width (nm)	4.1	4.0 ± 1.7	4.8 ± 1.3

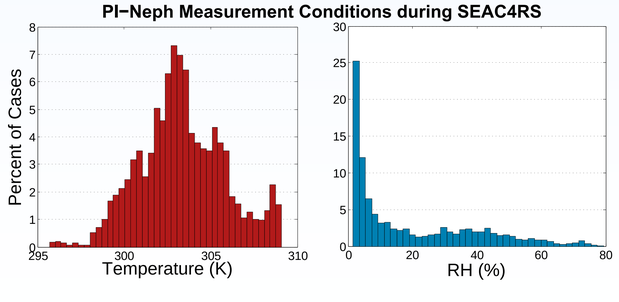


PI-Neph during SEAC4RS

The PI-Neph obtained high quality data for all of the SEAC4RS science flights. Available products will be:

- **Scattering Phase Function (P_{11})**
- **Polarized Phase Function ($-P_{12}/P_{11}$)**
- **Scattering Coefficient (β_{scat})**
- **Asymmetry Parameter (g)**

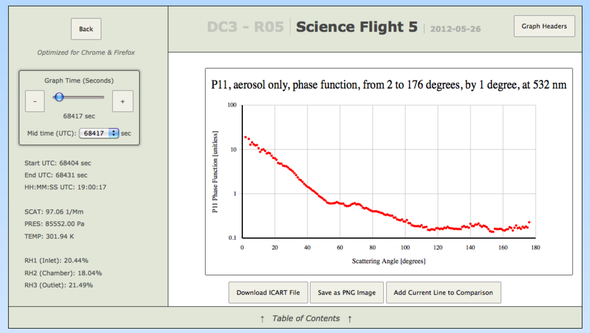
All products are available at 473nm, 532nm and 671nm and are measured from *3˚ to 176˚ in scattering angle*.

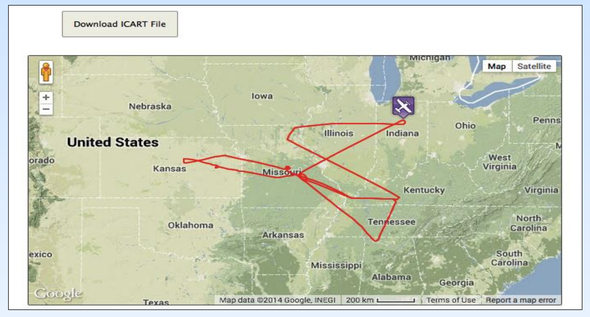


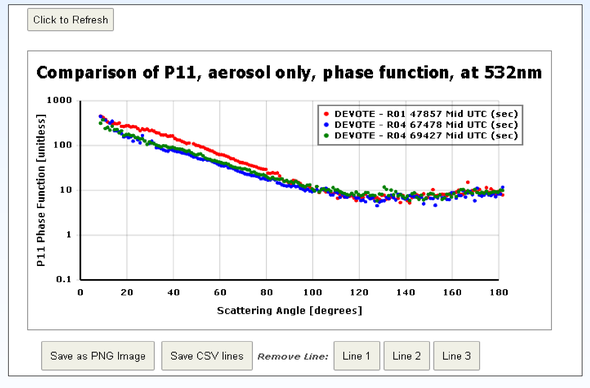
Data Visualization Toolkit

http://laco03.umbc.edu/pineph/
Password: QWOP89

All PI-Neph scattering data, including data from the most recent SEAC4RS flight campaign, is publicly available through LACO's web based data visualization system. This tool is capable of quickly displaying PI-Neph scattering measurements with the associated aircraft altitude and location as well as temperature, pressure, and relative humidity data for the sampled aerosol.







References

[1] Dubovik, O. *et al.* Accuracy assessments of aerosol optical properties retrieved from Aerosol Robotic Network (AERONET) Sun and sky radiance measurements. *J. Geophys. Res. Atmos.* **105,** 9791–9806 (2000).

[2] Mishchenko, M. I. *et al.* Accurate Monitoring of Terrestrial Aerosols and Total Solar Irradiance: Introducing the Glory Mission. *Bull. Am. Meteorol. Soc.* **88,** 677–691 (2007).

[3] Liou, K., Takano, Y. & Yang, P. *Light scattering and radiative transfer in ice crystal clouds: Applications to climate research. In Light Scattering by Nonspherical Particles: Theory, Measurements and Applications*. 417–449 (Acadamic Press, 1999).

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